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Productive performance and blood parameters of bulls fed diets containing babassu mesocarp bran and whole or ground corn

Aline Evangelista Machado Santana[1], José Neuman Miranda Neiva[1], João Restle[1], Fabrícia Rocha Chaves Miotto[1], Luciano Fernandes Sousa[1], Vera Lúcia de Araújo[1], Ranniere Rodrigues Pereira Parente[1], Rhaiza Alves Oliveira[1]

[1] *Universidade Federal do Tocantins, Escola de Medicina Veterinária e Zootecnia, Araguaína, TO, Brasil.*

ABSTRACT - The objective of the present study was to evaluate the effects of corn milling and the inclusion of babassu mesocarp bran (BMB) on productive performance, digestibility of dietary nutrients, and blood parameters of dairy crossbred (Holstein-Gyr) bulls finished in confinement. Twenty-four bulls were fed four different experimental diets, containing two levels of inclusion of BMB (0 and 41.24%) and corn supplied in two different forms (ground and whole), for 98 days (77 days of data collection and 21 days of adaptation). The intakes and digestibility coefficients of the dry matter (DM) and nutrients were determined. There were no significant interaction effects of the BMB inclusion level and the form of corn used on the performance and digestibility variables. The intakes of DM, crude protein (CP), and neutral detergent fibre (NDF) increased with the inclusion of BMB in the diets. However, the inclusion of BMB in the diets decreased the ether extract intake, the NDF apparent digestibility, and the feed efficiency of DM and CP. Dry matter and NDF intakes also increased with the use of ground corn in the diet, which promoted an increase in the intake of total digestible nutrients (TDN), digestibility of non-fibrous carbohydrates, and average daily gain. However, the supply of ground corn reduced the feed efficiency of TDN. The remaining measured variables did not vary with the tested diets. The levels of plasma protein and albumin remained normal, but glucose concentrations were always high, irrespective of the tested diet. The form of corn supplied and the level of BMB inclusion had a significant interaction effect on the levels of triglycerides, urea, aspartate aminotransferase, and alkaline phosphatase. Babassu mesocarp bran can be included up to 41.24% in the diet of confined bulls without a negative effect on the animal weight gain. Corn should be supplied ground because this form improves the performance of crossbred bulls.

Key Words: average daily gain, digestibility, dry matter intake, efficiency, neutral detergent fibre intake

Introduction

Corn is the main food used in animal production and therefore the main source of starch used in animal nutrition. However, the use of corn is becoming increasingly more expensive for producers due to its increasing market price as a result of the worldwide growth of biofuel production (Wallington et al., 2012). The increase in demand for corn affects its market value and motivates the search for products with lower commercial value that may replace it, such as agro-industrial by-products, which exist in large quantities in the market and have high potential for use in animal feeding.

Babassu mesocarp bran (BMB) is one of those by-products, with an average of 67% of total digestible nutrients (TDN). Favourable results have been obtained for the use of BMB as a substitute for corn in cattle feeding (Miotto et al., 2013). Babassu mesocarp bran is a by-product of the production of babassu oil. This oil is present in the almonds of the coconut of the babassu palm tree (*Orbignya sp.*) and is used for human consumption and cosmetics production. The native babassu coconut is formed of the epicarp (11%), which is the fibrous outer layer of the fruit; the mesocarp (23%), an intermediate portion with high starch and fibre concentrations that can be used for the production of ethanol and animal feed; the endocarp (59%), which has a high lignin concentration and is used for the production of charcoal; and the almonds (7%), from which the oil is extracted (Nascimento, 2004). Babassu mesocarp bran is produced by separating, milling, and sieving the mesocarp, and has small particles and an average concentration of NDF of 45% of the dry matter. Although BMB has a high percentage of fibre, the results obtained regarding its use are promising. In addition, the high fibre content may make BMB a good option when high-concentrate diets are used because by-products with high fibre concentrations do not induce production of lactate, thereby decreasing the occurrence of problems such as acidosis (Katsuki, 2009).

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Corresponding author: araguaia2007@gmail.com
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Currently, the exploitation of the coconut of the native babassu palm is one of the main forms of income of small farmers of the Brazilian Amazon, and therefore, has great economic and social importance, with low environmental impact. An increase in alternatives for the use of babassu by-products may have a positive impact on the economy of this region.

Another possible strategy for the reduction of the cost of diets with high levels of concentrate is the use of whole grains because in addition to reducing the expenses of food processing, the whole grain of corn is an interesting option for producers using diets with low concentrations of roughage due to its particle size.

The objective of the present study was to evaluate the effects of corn milling and of the inclusion of BMB on the diet digestibility and productive performance of confined dairy crossbred bulls.

Material and Methods

The experiment was conducted in the municipality of Araguaína/TO, Brazil, located at 07º11'28" South latitude, 48º12'26" West longitude and elevation of 227 m. The local climate is tropical humid and the precipitation was 42 mm; maximum and minimum temperatures were 32.77 and 18.7 ºC, respectively; average temperature was 25.05 ºC; and relative humidity was 76.75%, from April to July 2011.

A completely randomised experimental design was used, with a 2 × 2 factorial arrangement (two levels of BMB and two forms of corn) with six replicates (animals) per treatment. Twenty-four dairy crossbred (Holstein - Gyr) bulls at approximately 3 years of age and with average initial weight of 307.35 kg were used. The total confinement period was 98 days, 77 days of which were used for data collection and 21 days consisted of adaptation of the animals to the tested diets and the individual stalls. During the adaptation period, the animals were treated against endo- and ectoparasites and received injectable A, D, and E vitamins. The animals were weighed individually at the beginning and the end of the experiment, in the morning, without previous fasting. The obtained weights were considered as the initial weight (IW) and the slaughter weight (SW), respectively. The diets were formulated according to the NRC (2001) to contain similar protein levels and to achieve an average daily gain of 1.2 kg/day (Table 2).

The feed was supplied as a total diet once daily, at 14.00 h, in a quantity allowing between 5 and 10% leftovers of the total supplied. Millet silage was used as roughage (Table 1). Samples of the leftovers and of the supplied feed were collected weekly for analysis. Blood samples of each animal were collected each 21 days through puncture of the jugular vein, using Vacutainer tubes. For the determination of glucose concentrations, the blood was collected in tubes containing sodium fluoride. The blood samples were cooled and taken to the laboratory, where they were centrifuged at 2,000 g for 15 min to separate the plasma from the serum, which was then placed in Eppendorf tubes, labelled, and stored at −20 ºC. Triglycerides, total cholesterol, total protein,

Table 1 - Chemical composition of the feeds utilized in the experimental diets

g/kg DM	Millet silage	Corn	Soybean meal	BMB
Dry matter[1]	180.5	854.1	864.2	884.2
Crude protein	70.1	60.8	446.2	34.5
Ether extract	12.7	33.9	13.3	8.1
Neutral detergent fibre	659.5	101.1	156.9	463.7
Acid detergent fibre	448.3	35.6	95.6	359.8
Hemicellulose	211.2	65.5	61.3	103.9
Non-fibrous carbohydrates	155.4	790.8	341.6	452.1
Total carbohydrates	814.9	891.9	498.5	915.8
Lignin[2]	26.5	10.5	24.5	119.5
Ash	102.3	13.4	42.0	41.6

BMB - babassu mesocarp bran.
[1] g/kg natural matter.
[2] Acid detergent lignin.

Table 2 - Composition of the experimental diets

Ingredients, in g/kg DM	Ground corn		Whole corn	
	0 BMB	412.4 BMB	0 BMB	412.4 BMB
	Percentage composition			
Millet silage	72.0	72.0	72.0	72.0
Ground corn	818.7	360.8	0.00	0.00
Whole corn	0.00	0.00	818.7	360.8
Soybean meal	78.3	121.8	78.3	121.8
Babassu mesocarp bran	0.00	412.4	0.00	412.4
Minerals[1]	18.6	20.6	18.6	20.6
Urea	12.4	12.4	12.4	12.4
	Chemical composition			
Dry matter[2]	790.2	787.4	788.4	798.1
Crude protein	112.2	112.6	117.1	114.7
Ether extract	37.8	22.3	38.6	21.9
Neutral detergent fiber	170.2	285.5	168.1	282.4
Acid detergent fiber	79.5	215.1	78.9	219.6
Hemicellulose	90.7	70.4	89.2	62.8
Non-fibrous carbohydrates	641.4	520.8	636.7	51.96
Total carbohydrates	811.6	806.3	804.8	802.0
Lignin[3]	13.6	40.4	14.0	41.2
NDIN[4]	134.4	214.9	144.7	218.7
ADIN[4]	102.4	195.8	109.8	208.0
Ash	38.4	58.8	39.5	61.4

BMB - babassu mesocarp bran; DM - dry matter; NDIN - neutral detergent insoluble nitrogen; ADIN - acid detergent insoluble nitrogen.
[1] 188.0 g/kg calcium; 74.0 g/kg sulfur; 24.0 g/kg phosphorus; 30.0 g/kg magnesium; 60 g/kg sodium; 24 mg/kg cobalt; 240 mg/kg fluorine; 720 mg/kg copper; 40 mg/kg iodine; 1,500 mg/kg manganese; 8 mg/kg selenium; 2,080 mg/kg zinc; and 1,830 mg/kg monensin sodium.
[2] g/kg natural matter.
[3] Acid detergent lignin.
[4] g/kg of total nitrogen.

urea, albumin, creatinine, aspartate aminotransferase, alkaline phosphatase, and glucose levels were determined in the collected samples using commercial kits.

At the end of the experiment, the apparent digestibility of the dry matter and of the nutrients was evaluated. Samples of the leftovers, feed, and faeces were collected on three consecutive days and used for the determination of dry matter (DM), organic matter, crude protein (CP) (Method 920.87; AOAC, 1990) and ash (Method 924.05; AOAC, 1990). The concentrations of neutral detergent fibre (NDF), analyzed using heat-stable alpha-amylase and expressed inclusive of residual ash, acid detergent fibre (ADF) expressed inclusive of residual ash, and lignin using solubilisation of cellulose with sulphuric acid were determined according to Van Soest (1973) and Van Soest et al. (1991). The ether extract percentage (EE) was determined by washing the samples with petroleum ether at 90 ºC for one hour according to the methodology recommended by the appliance manufacturer (ANKOM, 2009). The levels of non-fibrous carbohydrates (NFC), total carbohydrates (TC), and total digestible nutrients (TDN) were calculated according to Sniffen et al. (1992), where TC = 100 – (%CP + %EE + %ash), NFC = TC – NDF, and observed TDN = DCP + (DEE × 2.25) + TDC, where DCP = digestible crude protein; DEE = digestible ether extract; and TDC = total digestible carbohydrates.

The faeces production was estimated according to the internal-marker technique (Cochran et al., 1986) using indigestible neutral detergent fibre (iNDF) as the marker (Casali et al., 2008). The values obtained from the analyses were used to calculate the dry matter, crude protein, ether extract, neutral detergent fibre, non-fibrous carbohydrates, and total digestible nutrient intakes and the respective apparent digestibility coefficients. The intakes were expressed in kilograms per day (kg/day) and/or as a percentage of the live weight (% LW). The average daily gain and the feed efficiency dry matter (kg ADG/kg DM intake), crude protein (kg ADG/kg CP intake), and total digestible nutrients (kg ADG/kg TDN intake) were also calculated.

The data were subjected to homoscedasticity and normality tests. For every quantitative variable that was normal, an analysis of variance was performed, and the Pearson product moment correlation coefficients were calculated. The initial weight was used as a covariate, and when its effect was not significant, this factor was removed from the model. The mathematical model was represented by:

$$\gamma ijk = \mu + \tau i + \delta j + \tau i*\delta j + \beta k + a ij,$$

in which: γijk = the dependent variable; μ = overall mean; τi = effect of factor i (inclusion level of babassu mesocarp bran); δj = effect of factor j (corn processing form); ($\tau i*\delta j$) = interaction between factor i and factor j; βk = effect of initial weight k; $a ij$ = experimental residual error associated with the factorial BMB inclusion level and physical form of corn. When the interaction between the tested factors was not significant (above 5% of significance), Tukey's test was used to test for significant differences between means at P<0.1.

Results

Although the inclusion of BMB and the processing of the corn grain had significant effects on the measured variables, there were no significant interactions between the two factors (P>0.05) (Table 3). The dry matter intake (DMI) was higher for the diets with BMB inclusion, when expressed both in kg/day (P = 0.022) and as a live weight percentage (LW) (P = 0.012). The form of corn used had a significant effect on DMI, when expressed both in kg/day (P = 0.063) and % LW (P = 0.051). The crude protein intake (CPI) was higher (P = 0.001) for the animals fed the diets containing BMB, regardless of the form of corn used, and there was a positive significant correlation between CPI and DMI (r = 0.757, P<0.001) (Table 4).

The neutral detergent fibre intake (NDFI) was 54% higher (P = 0.001) for the diets with BMB than for the diets where corn was the only energy source. Similarly, the NDFI also differed according to the form of corn used (P = 0.024) and was 13% higher when ground corn

Table 3 - Nutrient intake by crossbred bulls fed the experimental diets

Variables	Ground corn		Whole corn		CV, %	P-value		
	0	412.4	0	412.4		BMB	CoP	BMB × CoP
DMI, kg/day	8.38	13.21	8.33	9.16	16.13	0.022	0.063	0.081
DMI, % LW	1.96	2.97	1.97	2.23	11.76	0.012	0.051	0.062
CPI, kg/day	0.75	0.99	0.67	1.05	17.27	0.001	0.932	0.251
NDFI, % LW	0.27	0.58	0.23	0.51	14.38	0.001	0.024	0.651
NFCI, kg/day	4.5	4.91	4.37	4.62	15.60	0.273	0.492	0.789
EEI, kg/day	0.28	0.23	0.27	0.2	15.28	0.001	0.293	0.536
TDNI, kg/day	5.77	6.67	4.92	5.41	20.99	0.173	0.045	0.678

CV - coefficient of variation; BMB - babassu mesocarp bran; CoP - corn processing; DMI - dry matter intake; CPI - crude protein intake; NDFI - neutral detergent fibre intake; NFCI - non-fibrous carbohydrates intake; EEI - ether extract intake; TDNI - total digestible nutrients intake.

Table 4 - Pearson's correlation among nutrient intake, apparent digestibility, and feed efficiency of crossbred bulls fed the experimental diets

	AD_{CP}	NDFI	AD_{NDF}	EEI	AD_{NFC}	TDNI	TDN	DMI	AD_{DM}	FE_{CP}	FE_{DM}	FE_{TDN}
CPI	0.269	0.833**	–0.007	0.143	0.205	0.790**	–0.129	0.756**	–0.143	–0.960**	–0.533*	–0.736
AD_{CP}		–0.067	0.569*	0.545*	0.750**	0.629*	0.722**	0.258	0.746**	–0.283	0.360*	–0.707**
NDFI			–0.049	–0.197	0.136	0.581	–0.201	0.705**	–0.301	–0.832**	–0.735**	–0.499*
AD_{NDF}				0.556*	0.560*	0.388*	0.818**	0.087	0.521*	–0.056	0.220	–0.391*
EEI					0.399*	0.586*	0.568*	0.256	0.531*	–0.182	0.468*	–0.555*
AD_{NFC}						0.630*	0.794**	0.325	0.749**	–0.309	0.253	–0.701**
TDNI							0.407*	0.770**	0.398*	–0.797**	–0.121	–0.945**
TDN								0.037	0.783**	0.051	0.425	–0.422*
DMI									0.262	–0.735**	–0.275	–0.738**
AD_{DM}										0.119	0.5721*	–0.461*
FE_{CP}											0.462*	0.798**
FE_{DM}												0.001

*P<0.05; **P<0.001.

CPI - crude protein intake in kg/day; AD_{CP} - apparent digestibility of crude protein; NDFI - neutral detergent fibre intake; AD_{NDF} - apparent digestibility of neutral detergent fibre; EEI - ether extract intake; AD_{NFC} - apparent digestibility of non-fibrous carbohydrates; TDNI - total digestible nutrients intake; TDN - total digestible nutrients; DMI - dry matter intake; AD_{DM} - apparent digestibility of dry matter; FE_{CP} - feed efficiency of crude protein; FE_{DM} - feed efficiency of dry matter; FE_{TDN} - feed efficiency of total digestible nutrients.

was supplied as compared with the supply of whole corn. The NDFI was significantly positively correlated with DMI (r = 0.704, P<0.001). There were no significant effects of the inclusion of BMB or the corn processing on the non-fibrous carbohydrate intake (NFCI) (P>0.1). The intake of ether extract (EEI) was significantly lower for the diet with 41.24% BMB than for the diets without BMB (P = 0.001). Although an increase in DMI was observed with the diets with BMB, this increase was not enough to increase the EEI, and there was a negative correlation between these two variables (r = −0.399, P = 0.053).

The intake of total digestible nutrients (TDNI) was influenced by the form of corn supplied (P = 0.045) and was lower for the diets in which the corn was supplied whole, regardless of the level of inclusion of BMB. The TDNI was not correlated with the apparent digestibility of dry matter (AD_{DM}) but was significantly positively correlated with the concentration of total digestible nutrients (TDN) in the diets (r = 0.407, P = 0.048) and with the apparent digestibility of crude protein (AD_{CP}) (r = 0.629, P = 0.001), indicating that diets with higher digestibility of these nutrients also had higher TDNI.

Although both the inclusion of BMB and the processing of the corn grain had significant effects on the apparent digestibility of dry matter and nutrients, there were no significant interactions between the two factors (P>0.05) (Table 5). The average values for the AD_{DM}, AD_{CP}, and ether extract digestibility (AD_{EE}) were 0.602, 0.608, and 0.830, respectively, and were not affected by the tested diets (P>0.1), while the inclusion of BMB in the diet resulted in decrease in the apparent digestibility of the neutral detergent fibre (AD_{NDF}) (P = 0.056). The apparent digestibility of non-fibrous carbohydrates (AD_{NFC}) was influenced by the form of corn supplied (P = 0.001), and it was lower for the diets in which the corn was supplied whole, irrespective of the inclusion of BMB.

The TDN was significantly affected by the form of corn supplied (P = 0.041) and was higher for the diets with ground corn (652 g/kg DM) than for the diets with whole corn (610.6 g/kg DM), regardless of the level of inclusion of BMB. The change in TDN percentage was positively correlated with the AD_{CP} (r = 0.722, P<0.001), AD_{NDF} (r = 0.818, P<0.001), and AD_{NFC} (r = 0.794, P<0.001).

The tested factors had no significant effects on the slaughter weight (SW) of the animals (P>0.05) (Table 6). However, the average daily gain (ADG) was significantly lower for the animals supplied with whole-corn diets (P = 0.083). The ADG was significantly positively correlated with the TDNI (r = 0.549, P = 0.005), indicating that the intake of higher nutrient quantities resulted in an increase in animal weight gain (Table 4). The feed efficiencies of dry matter (FE_{DM}) (P = 0.001) and crude protein (FE_{CP}) (P = 0.001) decreased with the inclusion of BMB (Table 6). Negative correlations were observed between FE_{DM} and NDFI (r = −0.735, P<0.001) and between FE_{CP} and CPI in kg/day (r = −0.9603, P<0.001) and DMI in kg/day (r = −0.7069, P<0.001). The weight gain decreased for the diets with BMB inclusion, even though the dry matter and crude protein intakes were similar for both diets, irrespective of the form of corn supplied. The form of corn supplied had a significant effect on the feed efficiency of total digestible nutrients (FE_{TDN}) (P = 0.032). The FE_{TDN} was significantly lower when ground corn was supplied than when whole corn was supplied and was negatively correlated with TDNI (r = –0.803, P<0.001) (Table 4).

The total cholesterol and albumin levels did not change significantly with the inclusion of BMB or with the corn processing (P>0.1) and averaged 102.74 mg/dL and 3.81 g/dL, respectively (Table 7). The total glucose and total protein concentrations were lower in the animals fed the diets containing BMB. There were significant interaction effects between the form of corn supplied and the BMB inclusion on the levels of triglycerides (P = 0.0019), urea (P = 0.0277), aspartate aminotransferase (P = 0.0504), and alkaline phosphatase (P = 0.0387). The concentration of circulating aspartate aminotransferase increased with the supply of whole corn in combination with the inclusion of BMB. The urea concentration remained high with the supply of ground corn and BMB, but for the diets in which corn was the main energy source, the use of ground corn decreased the concentration of circulating urea. The concentration of plasma triglycerides remained high with the use of ground corn in the diets in which corn was the main energy source, whereas the inclusion of BMB associated with the supply of ground corn led to a decrease in the triglycerides concentration. These results were in contrast with the alkaline phosphatase averages, which remained above the normal levels for the species, irrespective of the tested factors.

The concentrations of plasma total protein (P = 0.0002) and serum glucose (P = 0.0054) decreased with the inclusion of BMB in diets irrespective of the corn form used. The creatinine levels were significantly affected by the form of corn used (P = 0.0048), with the supply of whole corn resulting in higher concentrations of plasma creatinine.

Table 5 - Apparent digestibility coefficients of the nutrients of crossbred bulls fed the experimental diets

Variables	Ground corn		Whole corn		CV, %	P-value		
	0	412.4	0	412.4		BMB	CoP	BMB × CoP
AD_{DM}	0.619	0.624	0.582	0.582	14.22	0.942	0.281	0.949
AD_{CP}	0.676	0.597	0.591	0.567	14.51	0.176	0.133	0.458
AD_{NDF}	0.594	0.486	0.505	0.460	22.96	0.056	0.119	0.808
AD_{EE}	0.897	0.920	0.786	0.717	17.12	0.695	0.105	0.446
AD_{NFC}	0.893	0.871	0.791	0.793	4.05	0.474	0.001	0.409
TDN, g/kg DM	655.6	648.4	630.7	590.6	7.24	0.224	0.041	0.393

BMB - babassu mesocarp bran; CoP - corn processing; AD_{DM} - apparent digestibility of dry matter; AD_{CP} - apparent digestibility of crude protein; AD_{NDF} - apparent digestibility of neutral detergent fibre; AD_{EE} - apparent digestibility of ether extract; AD_{NFC} - apparent digestibility of non-fibrous carbohydrates; TDN - total digestible nutrients.

Table 6 - Productive performance of crossbred bulls fed the experimental diets

Variables	Ground corn		Whole corn		CV, %	P-value		
	0	412.4	0	412.4		BMB	CoP	BMB × CoP
Initial weight, kg	302.58	305.75	304.00	317.08	-	-	-	-
Slaughter weight, kg	447.43	423.97	419.44	418.57	10.98	0.536	0.401	0.564
Average daily gain, kg	1.64	1.78	1.59	1.21	22.88	0.539	0.083	0.112
FE_{DM}	0.18	0.14	0.18	0.12	14.21	0.0001	0.312	0.359
FE_{CP}	2.45	1.85	2.82	1.80	17.28	0.0001	0.325	0.216
FE_{TDN}	0.32	0.27	0.39	0.35	24.29	0.242	0.032	0.919

BMB - babassu mesocarp bran; CoP - corn processing; FE_{DM} - feed efficiency of dry matter; FE_{CP} - feed efficiency of crude protein; FE_{TDN} - feed efficiency of total digestible nutrients.

Table 7 - Blood parameters of crossbred bulls fed the experimental diets

Variables	Ground corn		Whole corn		CV, %	P-value		
	0	412.4	0	412.4		BMB	CoP	BMB × CoP
Glucose (mg/dL)	98.87	86.47	93.18	82.62	5.47	0.005	0.139	0.77
Total cholesterol (mg/dL)	115.44	96.18	88.44	110.89	22.19	0.908	0.655	0.181
Triglycerides (mg/dL)	20.17	9.91	14.72	15.61	12.39	0.004	0.91	0.002
Total protein (g/dL)	7.25	6.18	7.41	6.21	3.96	0.0002	0.553	0.711
Albumin (g/dL)	3.84	3.98	3.66	3.77	6.48	0.412	0.212	0.941
Urea (mg/dL)	28.54	46.09	39.14	33.15	18.80	0.195	0.777	0.028
AST (U/L)	74.75	65.09	72.45	97.15	15.30	0.313	0.066	0.05
AKP (U/L)	301.08	426.52	385.25	270.67	22.21	0.907	0.446	0.039
Creatinine (mg/dL)	1.50	1.46	1.67	1.67	5.09	0.616	0.005	0.67

BMB - babassu mesocarp bran; CoP - corn processing; AST - aspartate aminotransferase; AKP - alkaline phosphatase.

Discussion

According to the NRC (1996), the animal DMI may vary with body composition, sex, age, physiological state, handling, and diet characteristics (granulometry, humidity, and nutritional value). Of the diet characteristics, the nutritional value has a great influence on DMI. The supply of diets with a high fibre percentage may change the DMI due to ruminal fill or to the fact that when a diet has low nutritional value, the animals tend to increase their DMI to meet their nutritional requirements (Forbes, 1995).

This behaviour was observed in the present study, because BMB has a higher NDF percentage, and therefore a lower energy value, than corn, which reduced the nutritional value (lower TDN percentage) of the diets with 41.24% BMB and thus promoted the increase in DMI. Regardless of the variations in DMI for the diets with BMB and ground corn, no difference was observed between the diets with BMB and whole corn and the diets without BMB. This lack of difference indicates that the use of whole corn, even though it was mixed with the BMB, allowed the animals to select it. Because corn has a high energy value, this corn selection decreased the animals need for greater DM intake to meet their nutritional demands. Conversely, when the corn was supplied ground, the decrease in particle size prevented its selection, thus contributing to the increase in DMI.

Although there was an increase in the amount of ingested fibre with the inclusion of BMB, this increase was not a limiting factor for DMI. This result may have been caused by the high rumen passage rate of the fibre present in the BMB, which has a very small particle size, with 96% of the particle smaller than 1.67 mm (Miotto et al., 2013). Because the fibre present in the BMB did not contain long fibres, which could result in a decrease in DMI, it did not cause ruminal fill. The observed increase in CPI upon the inclusion of BMB was therefore a consequence of the higher DM intake because the diets had similar protein contents. The increased DMI resulted in increased CPI, as indicated by the correlation between DMI and CPI.

The fact that BMB (46.37% NDF) had higher levels of NDF than corn (10.11% NDF) resulted in higher fibre intake. The higher NDFI would therefore be evident even without a difference in the amount of DM consumed by the animals. However, the positive correlation between NDFI and DMI indicates the contribution of the DM to increase the intake of the fibre fraction of the diet, which has been proven in the work of Silva et al. (2012), who used 66% concentrate in DM and tested the inclusion of 0, 20, 40, and 60% BMB in the concentrate. The authors observed a linear increase in the NDF intake with increasing levels of BMB inclusion in the diet.

The inclusion of BMB and the corn processing did not affect the NFCI. The increase in the intake of dry matter most likely compensated for the lower concentration of NFC in the BMB. Using ½ Brown Swiss and ½ Nellore and 0, 25, 50, 75, and 100% BMB in substitution of corn, Miotto et al. (2013) observed that the inclusion of BMB up to the level of 46.7% increased the NFCI. For higher inclusion levels, there was a decrease in the intake as a consequence of the decrease in the quantity of NFC supplied to the animals, which is in contrast with the present study. The fact that the aforementioned authors used a greater volume of roughage than in the present study may have contributed to reduce the levels of NFC in the diet and consequently its intake by the animals. The decrease in EEI observed in the diets with BMB was a consequence of the decrease in the amount of ether extract in the diet, as a result of the low level of EE present in the composition of BMB (0.81%). This pattern was also observed by Miotto et al. (2013), who also did not observe changes in TDNI with inclusion of BMB up to 65% of the total dietary DM. Although BMB has lower digestibility than corn, the increase in DMI could have compensated for the decrease in TDN in the diet.

The similar values of AD_{DM} indicated that regardless of the corn grains being supplied whole and of the inclusion of BMB, the process of digestion of these foods was not negatively affected. This result is in agreement with the study of Owens (2005), who considered that the use of ground corn, compared with whole corn, in sheep diets, was not enough to guarantee improvements in the AD_{DM} of corn. Gorocica-Buenfil and Loerch (2005) tested the supply of corn in different forms to animals of several ages and did not observe variations in the apparent digestibility of DM, CP, NDF, and ADF with the age of the animals or with the form of corn supplied (ground or whole). However, regarding the inclusion of BMB, the similarities in the results are due to the low level of inclusion of the tested bran since in other studies using higher levels of BMB, the authors found a reduction in AD_{DM} (Miotto et al., 2013; Alencar, 2014), and associated this result with the increase of the fibre fraction, especially lignin, in the diet. It is therefore possible that the adoption of a higher level of BMB resulted in a decrease in AD_{DM}.

Although the diets with BMB presented higher ADIN levels than the diets without bran inclusion (Table 2), which could limit the AD_{CP} due to higher lignin concentrations (Van Soest, 1994), this difference did not negatively affect the AD_{CP}, which had similar average values for all the tested diets. It is possible that all the tested diets have the same non-protein nitrogen concentration, in which case the use of a true protein source (soybean meal) as reference for the normalisation of the protein concentration may have been sufficient to guarantee the adequate use of the CP present in the diet, with a synchronisation between the degradation of the protein and of the carbohydrates, resulting in similar AD_{CP} levels in the diets with and without BMB.

It is possible that the lower AD_{NDF} observed in the diets with BMB are related to the reduced particle size of this food. According to Soares et al. (2001), very small particles may possess lower ruminal degradation rates and consequently lower total digestibility because they remain in the rumen for a shorter time than larger particles, going through the reticulo-omasal orifice with the liquid diet fraction (Zinn and Garces, 2006). Because the capacity of ruminants to digest fibre is mainly associated with the ruminal digestion, this lower time of permanence in the rumen results in a decreased capacity to digest the fibre food fraction (Van Soest, 1994). Furthermore, BMB had a higher lignin concentration than corn (7.80 and 1.16, respectively), which contributed to the lower digestibility of the fibre fraction because the ruminal microorganisms cannot digest lignin or the food fractions associated with lignin, resulting in a negative correlation between the lignin percentage and AD_{NDF} (Smith et al., 1972).

Although larger particles remain for a longer period of time in the rumen (Forbes, 1995), the type of grain used in the present work (whole flint corn) may have resulted in lower NFC digestibility due to difficulty of using the starch present in the grain for the rumen microorganisms (Bulle et al., 2002). In the case of flint corn, the larger part of the starch is located in the glassy endosperm, which is coated with a protein matrix that reduces its fermentation (Owens, 2005) and acts as a barrier to the adherence to starch and starch hydrolysis by the rumen bacteria (Kozloski, 2011). In the diets with ground corn, the corn milling may have allowed an increase in contact surface and therefore in available area for the adherence of the rumen microorganisms and partial rupture of the protein matrix, resulting in a higher NFC digestibility (Corona et al., 2005), which did not occur when whole corn was used. The increase in TDN concentration is therefore the result of an increased access of rumen microorganisms to starch and greater starch digestibility. The diets that presented higher digestibility of these nutrients also presented higher percentage of TDN (Zinn et al., 1997) because the AD_{CP}, AD_{TC}, and AD_{EE} are used in the calculation of TDN (Sniffen et al., 1992). The diet concentration of TDN represents its energy value and is important for an adequately balanced diet, whereas diets high in concentrate food normally present high levels of TDN while the increase in fibre content reduces the content found.

Because animal performance is mostly related to the intake of digestible dry matter, the observed changes in nutrient intake and digestibility resulted in variations in animal performance (Mertens, 1994). Higher nutrient intake results in an increase in nutrient availability in the tissues and in greater weight gain. Therefore, the quantity of ingested TDN directly influenced the weight gain, wherein the reduction in intake of TDN observed in the diets when corn was supplied whole resulted in a decrease in ADG. The fact that no differences were observed between the diets with 0 and 41.24% of BMB, however, indicates that the observed increase in DMI in the diet with BMB was due to the need to compensate for the reduction in the energy value of this diet as the DMI increase did not result in increases of TDNI.

The decrease in the FE_{DM} of animals fed BMB was a consequence of the increase in DMI to meet the energy requirements, which resulted from the decrease in the dietary energy density with BMB. Gorocica-Buenfil and Loerch (2005) also reported a decrease in FE_{DM} with higher-fibre diets compared with diets with lower fibre concentrations, which averaged 190 and 197 g gain/kg DM intake, respectively. The inclusion of BMB was also responsible for the increase in CP intake; because the diets had similar nitrogen contents, the increase in DMI resulted in an increase in CPI. This difference resulted in a lower efficiency of the diets with BMB, which was a consequence of the lower weight gain obtained for the same amount of ingested CP.

In the diets in which the TDN intake was greater (ground corn), there was a reduction in the use efficiency of TDN, with a negative correlation between TDNI and the FE_{TDN}, which was because the higher TDNI was not converted into an increase in slaughter weight of the animals. Because FE_{TDN} is a ratio between TDN intake and the weight gain, a decrease in intake without a change in weight gain, as observed in the diets in which whole corn was supplied to the animals, results in an increase in the use efficiency of these nutrients.

Although a significant interaction was observed in the levels of aspartate aminotransferase, the variation was within normal values (48 to 100 U/L) (Meyer and Marvey, 1998). The concentration of alkaline phosphatase was always above the normal levels for the species, which are 29 to 99 U/L (Meyer and Marvey, 1998). This enzyme is involved in the ion exchange at the plasma membrane, and these results may indicate high metabolic activity (Gandra et al., 2009) leading to high synthesis of this enzyme

(Stojevic et al., 2005) as well as possible necrosis and rupture of the hepatocytes membranes, which increases the membrane permeability and may result in changes in the liver activity (Kaneko et al., 1997; Thrall et al., 2006).

Although a decrease in the percentage of glucose was observed with the inclusion of BMB, the serum concentration of this metabolite remained higher than the values considered normal for this species, regardless of the bran inclusion. This pattern may have been related to the high level of concentrate used in the tested diets (92.8%), which can cause an increase in the levels of blood glucose due to the high production of propionate. High levels of propionate production are associated with diets with low fibre concentrations, which stimulate the proliferation of amylolytic bacteria, responsible for the increase in the production of propionate (Journet et al., 1995), wherein an increase in the levels of fibre caused by the inclusion of BMB possibly reduced production of this acid, resulting in reduction of blood glucose levels in animals fed the bran. This pattern is because the propionate is the main glucose precursor in ruminants (Martineau et al., 2007), responsible for approximately 65% of the circulating glucose (Herdt, 2000). This close relationship occurs because ruminants have low glucose-absorption capacity in the small intestine (González and Scheffer, 2002).

This change in the concentration of glucose most likely contributed to increasing the concentrations of circulating triglycerides and cholesterol, as a result of both the possible increase in the production of acetate with the inclusion of BMB and of lipogenesis (Trhall et al., 2006). Lipogenesis is stimulated by the release of insulin, which increases the lipid synthesis, thereby changing the concentration of circulating triglycerides and cholesterol when the levels of glucose are high (French and Kennelly, 1990).

Although the plasma total protein concentration varied with the tested diets, it was within the range of variation considered normal for adult cattle (Meyer and Marvey, 1998). Although the variation was significant, the measured concentrations of albumin, globulin, and fibrinogen, the main proteins present in plasma, were within normal levels (González and Scheffer, 2002). These results were confirmed by the concentrations of albumin, which were within the normal range for adult cattle (2.7 to 4.3g/dL) (Meyer and Marvey, 1998). Because a great part of the proteins present in plasma is synthesised in the liver, the results indicate that there were no lesions or damages leading to changes in the protein concentrations. In addition, the total protein concentration is related to the quantity of protein in the diet, and the fact that the results were normal indicates that the tested diets were correctly formulated given that the CP concentration in the diet did not result in increases in the plasma total protein concentration.

The concentrations of creatinine and urea are influenced by the activity of the renal system, and increases in the circulating levels of both of these variables indicate the impairment of the renal function (Finco, 1989). Although in some cases, changes in the concentration of creatinine are considered a consequence of the animal weight (Schroeder et al., 1990; Rennó et al., 2000), the levels of creatinine found in the present work did not increase with the weight. In fact, the highest creatinine concentrations were observed in the animals that were fed diets containing whole corn grain, which had numerically lower SW than the animals fed ground corn.

The tested factors had a significant interaction effect on the concentrations of urea. However, the urea concentration, which results from the amino acid catabolism and the recycling of ammonia at the rumen (González and Scheffer, 2002), remained high with all the tested diets (Meyer and Marvey, 1998), regardless of the BMB inclusion or the form of corn supplied. The observed increase in the urea concentration was possibly not related to changes in the activity of the renal system since creatinine levels remained normal in all evaluated treatments, but to the fact that the collection of blood samples was performed without previous fasting. This approach may have contributed to maintaining high levels of urea following the ingestion of food because the level of urea in the plasma is an indicator of the protein intake (González and Scheffer, 2002). Furthermore, the urea concentration remained high with the diet with ground corn and BMB, for which the intakes of dry matter and crude protein were high. However, it should be noted that the plasma creatinine is not a reliable test for the diagnostics of renal diseases because a very wide variation in the glomerular filtration rate is necessary for a change in the creatinine concentration to be noticeable (Finco, 1989; Thrall et al., 2006).

Conclusions

Babassu mesocarp bran may be included up to 41.24% in diets for confined crossbred bulls without compromising their weight gain. However, the use of babassu mesocarp bran results in a decrease in feed efficiency and digestibility of diet. Corn should be supplied ground because this form results in an improvement in the performance of crossbred bulls. The use of diets with a high percentage of concentrate promotes an increase in the circulating levels of alkaline phosphatase, which indicates high metabolic activity and may compromise the health of the animals if this diet is supplied for longer periods.

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